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Test Plan for Helicopter GPS Applications

Michael Magrogan

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16. Abstract

This test plan describes a project designed to collect data via flight testing from the Global Positioning System (GPS) when receivers are mounted on helicopters. GPS issues to be investigated include antenna location, satellite shielding, and multipath influences which might occur with rotorcraft applications in urban downtown areas. Minimum masking angle issues will also be addressed.

GPS integrated with other navigation and guidance systems such as microwave landing system (MLS) and Loran C will also be investigated. Both precision (P) and coarse/acquistion (C/A) code receivers will be evaluated. In addition, studies will be carried out to determine how to install a GPS antenna on composite body aircraft. Further studies may be related to automatic dependent surveillance functions. Future work will include evaluation of a GPS P code receiver as a reference for flight inspection. Keywords:

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TABLE OF CONTENTS

LIST OF TABLES

EXECUTIVE SUMMARY

This test plan describes a project designed to collect data via flight testing from the Global Positioning System (GPS) when receivers are mounted on helicopters. GPS issues to be investigated include antenna location, satellite shielding, and multipath influences which might occur with rotorcraft applications in urban downtown areas. Minimum masking angle issues will also be addressed.

GPS integrated with other navigation and guidance systems such as microwave landing system (MLS) and Loran C will also be investigated. Both precision (P) and coarse acquistion (C/A) code receivers will be evaluated. A P code GPS receiver will be examined as a possible candidate for a flight inspection reference system.

Laboratory testing with outside agencies will be conducted, provided funds are available, to determine the best location for the GPS receiver antenna on helicopters. In addition, studies will be carried out to determine how to install a GPS antenna on composite body aircraft. Some of this work will be accomplished in conjunction with an Interagency Agreement with the U.S. Army. Further studies may be related to automatic dependent surveillance functions.

INTRODUCTION

OBJECTIVES.

The primary goal of this flight test project is to address the technical issues concerning the use of the Global Positioning System (GPS) when GPS receivers are mounted on helicopters. To obtain this objective intermediate issues must be clarified.

1. The antenna location on helicopters must be investigated.

2. Satellite shielding in an urban environment must be investigated.

3. Multipath influences which might occur with rotorcraft applications in urban downtown areas must also be reviewed.

4. Minimum masking angles in an urban environment also must be determined.

5. Investigate GPS performance when integrated with other navigation and guidance systems such as microwave landing system (MLS) and Loran C.

6. Performance of both precision (P) and coarse/acquisition (C/A) code types of receivers must be reviewed.

7. Examine the case of a P code GPS receiver as a possible candidate for a flight inspection reference system.

8. Installation of a GPS antenna on composite body aircraft must be investigated.

Data will be collected by Federal Aviation Administration (FAA) Technical Center personnel using FAA aircraft and through an Interagency Agreement with the U.S. Army, and U.S. Army personnel and aircraft. If funding is available, laboratory testing with outside agencies will be conducted. These data will be used to determine the reliability, availability, and accuracy of the GPS signal. The methods used to gather data will be evaluated. Antenna location will be determined based on susceptibility to rotor modulation and signal strength variations.

BACKGROUND.

ROTARY WING AREA NAVIGATION. More than 6,000 helicopters operate in civil activities in the United States. Over half of these are engaged in commercial operations, such as short haul transport of people and materials. The remainder are engaged in business/corporate activities and local, state, and Federal Government operations. The unique ability of helicopters to operate efficiently at remote unprepared sites, either inland or offshore, and at low altitudes and steep glide slopes, impacts on the availability of line-of-sight communications and navigation aides commonly used by fixed wing aircraft. A navigation system providing nonsaturable, passive, and multidimensional global navigation guidance, independent of aircraft altitude as opposed to the present very high

frequency omnidirectional ranging distance measuring equipment (VOR/DME) navigation system, would enhance the area navigation capabilities of rotary wing aircraft.

GPS SYSTEM DESCRIPTION. The GPS is a Department of Defense (DOD) navigation concept whereby user position and time can be accurately determined from a minimum of four satellites placed in nonsynchronous but determinate orbits. The system is divided into three distinct segments:

1. The space segment includes a proposed contingent of 18 to 24 satellites placed in 10,900-mile radius, 12-hour elliptical orbits.

2. The user segment is a receiver/processor.

3. The control segment is currently comprised of five monitor stations, three upload stations, a master control station (MCS), and a backup MCS. The monitor stations are unmanned data collection centers under direct control of the MCS. The monitor stations provide information to the MCS to predict satellite position in the form of ephemeris data and satellite clock correction terms, which are uploaded daily to the satellites by the upload stations and transmitted from each satellite to the user equipment.

Four satellites above the horizon are normally required for GPS navigation. Ranges to the four satellites are determined by scaling the signal transit time with the speed of light. If the user clock is maintained precisely with GPS system time, only three satellites would be required for navigation. The user clock is less precise than the satellite clock, hence, less expensive. Therefore, a fourth satellite is required to resolve the bias between the imprecise user's clock and GPS system time.

GPS satellite signals are transmitted at two L-band frequencies, 1227.6 megahertz (MHz) (L2) and 1575.42 MHz (L1), to permit measurement of corrections for ionospheric delays with respect to signal propagation time. The signals are modulated with two pseudo-random codes, a P code which provides precise measurement of time, hence, precise position measurements, and a C/A code which provides less precise time measurement, but allows easy synchronization to the desired signal. The L1 signal is modulated in phase quadrature with both the P and the C/A codes. The L2 signal is modulated with the P code. Code patterns transmitted are unique to each space vehicle and are correlated with like codes in the user receiver. Satellite signal transmission transit time is measured by determining the code phase difference between the user and received sateilite codes.

Currently, plans call for civil use of the C/A code only. Furthermore, for national security reasons, the accuracy of the C/A code may be initially degraded to a level of 100 meters, 2 distance root mean squared (drms).

The DOD GPS program is divided into three phases:

1. Phase I, the Concept Validation Phase, verified the feasiblilty of determining precise user time and position from four ground aided satellites.

2. Phase II, the Full Scale Development Phase, currently with six operating satellites, is now in progress providing 2- to 4-hour intervals of four-satellite coverage over selected geographical areas.

3. Phase III, the Full Operational Capability Phase, where at least 18 satellites will be provided to permit nearly continuous worldwide navigation coverage, is expected to be fully implemented in the early 1990's.

TECHNICAL ISSUES.

Primary effects on transmitted signals depend upon frequency of the signal and conditions along the propagation path. L-band signals, such as those utilized by GPS, are susceptible to multipath interference, shielding effects, attenuation, and variable propagation delays These characteristics will be the subject of the proposed flight testing. Secondary effects related to specific user equipment, including antennas and receivers, will be addressed in studies with outside agencies through an Interagency Agreement with the U.S. Army and by the FAA Technical Center. The effects of satellite performance, uploads, and Control Segment actions, including denial of accuracy, will not be investigated except to note their existence and possible effect.

TEST PROCEDURES

The GPS signal will be evaluated by collecting airborne data to determine signal coverage and quality. Flights will be conducted in airport traffic areas, terminal areas, and along Instrument Flight Rules (IFR) routes.

Where possible, GPS procedures used in this flight test will be overlaid on existing procedures which are based on conventional navigation and guidance systems. This will facilitate direct comparison of the different systems, minimize the workload associated with implementing a new procedure, and minimize delays during the flight test by maintaining normal air traffic patterns.

Most of the flights will be conducted in the vicinity of the FAA Technical Center, Atlantic City International Airport, New Jersey. This will allow use of radar and laser tracking facilities. Site selection will be made based upon existence of large obstructions such as buildings or mountainous terrain in the area. These may cause signal blockage, multipath, or both. It is expected that flights will, therefore, be conducted over a large city and near a large mountain range, such as the Rockies. Also, flights will be conducted over large areas of flat terrain or large bodies of water where multipath may occur.

The procedures will be flown in an instrumented aircraft which will collect data on signal availability and accuracy. A precision tracking system will be utilized, where possible, to determine accuracy. These data may be used for this project and later projects which will investigate the use of GPS as an approach aid.

The separate effects which are of primary interest are identified and discussed below. Included is a short description of each and the means which will be

employed to evaluate it. As each group of tests is conducted it will be the subject of an Engineering Division report. These will detail the procedures and results of specific tests. At the conclusion of the test program, a final report will be issued which summarizes individual test results and conclusions, and recommends further steps to be taken as GPS implementation proceeds.

ANTENNA LOCATION.

Tests will be designed to determine the effect of rotor shading on the antenna. The method used will be to mount the antenna on a ground plane attached to a pole and to record data with the rotors stationary and turning at various positions along the length of the blades. Signal strength measurements will be used to determine the effect of shading. Metal and composite blade types will be examined for varying effects. Depending upon aircraft availibility, two blade, four blade, and more blade rotor systems will be examined. Laboratory testing will be conducted to determine the best location for the GPS receiver antenna. In addition, studies will be carried out to determine how to install a GPS antenna on composite body aircraft.

MULTIPATH.

Multipath interference may occur when a reflected signal arrives at a receiver in-phase with a nonreflected signal. It can result in inaccurate determination of position. Due to the correlation techniques used to track spread-spectrum signals, multipath can only occur when a reflective obstruction is within 1 1/2 chip lengths of the receiving antenna. This corresponds to a position error of approximately 4 meters for P code. The effect is magnified for C/A code due to the longer chip length and may result in errors on the order of 15 meters. Conventional antenna siting techniques virtually eliminate the danger of multipath for a fixed-site installation, such as a monitor site. For airborne use, vehicle dynamics greatly reduce the possiblity of multipath and insure that any effects, even if they do occur, will exist for only a brief period of time. Again, proper placement of the antenna will minimize the problem.

Multipath is considered to be a minor problem and its effects have not been well documented because of the difficulty in proving its effects. In order to perform a comprehensive investigation, however, it is necessary to accumulate a data base which will be used to form a decision on its potential to affect civil navigation.

In light of the above considerations, an attempt will be made during this flight test to induce multipath interference. The technique employed will be to fly at a family of constant angles relative to a reflective surface, such as a building or large body of water. The angle will be determined geometrically as that which will cause the signal from a particular satellite to be reflected at a constant angle and delayed by 1 to 1 1/2 chip lengths. Flight along this path will result in a biased position measurement if multipath is present. Otherwise, no degradation is expected to occur. C/A code will be used, if a suitable receiver is available, in order to increase the likelihood of mulitpath.

SHIELDING.

Shielding of the GPS signal will occur wherever obstructions are in the line of sight from the satellite to the user. The result will be complete blockage of the signal and loss of navigational data from the particular satellite being blocked. The blockage may be caused by objects which are very close, such as aircraft structure, or far away, such as terrain or foliage. Vehicle attitude may also cause loss of signal during cases where the aircraft itself causes blockage due to the antenna location.

The method used during this flight test will be to survey each test site for obstructions along the flightpath. These will then be combined with mathematical predictions of satellite position, for each site, to determine which satellites are expected to be available for navigation and at what times during the day. Flights will then be conducted during the times and in the areas of expected blockage. This will verify the model of satellite position and the existence of signal blockage. If this method results in acceptable estimates of signal availability, it will be proposed as a method of determining satellite coverage, subject to on-site verification.

MASKING ANGLE.

The masking angle is the minimum angle of satellite elevation at which that satellite's signal is usable for navigation. The main issue which must be resolved is to determine a minimum masking angle based upon system performance. This angle may be different for different users and will be determined jointly by the various segments of the GPS community.

Because satellites and antennas are not specified for operation below 5°, this is assumed to be a lower limit. However, conventional flight inspection methods require documentation of signal quality beyond the limits of coverage. It is, therefore, desired that this project provide data on signal quality above and below 5° elevation. Data will be collected at the lowest elevation angle possible with available equipment to help determine whether some other masking angle is appropriate and to document the effects outside the coverage area.

SIGNAL STRENGTH.

Signal levels have been determined to be nearly uniform over large areas of GPS coverage. This characteristic will be verified by collecting in-flight data and correlating it with data collected on the ground, in the local vicinity, by a fixed monitor receiver. This will document the signal strength in an area and help determine whether ground-based monitors provide a suitable means of assessing signal quality.

PROPAGATION DELAYS.

Propagation delays are caused by the implementation of the tropospheric and ionospheric models incorporated into the receiver processing software. Variance in actual delays which are based upon changing conditions are difficult to estimate in the receiver. These limitations become a dominant effect between 0° and 5° above the horizon when only one frequency is available. Receivers differ in their implementation due to the lack of a clearly optimal scheme for handling the problem. Use of navigational data from satellites below 5° elevation may be

restricted unless some clear operational advantage can be gained. A related minimal operational performance standard (MOPS) issue may be whether to inhibit use of low-elevation satellites or to prohibit the reselection of satellites for tracking during an approach. Data will be gathered during this flight test which may be used to support decisions of this nature. As a minimum, the performance of one particular receiver will be documented when satellites near the horizon are in use.

DATA COLLECTION PROCEDURES.

Before flying, a site survey will be conducted to determine where potential signal blockages may occur. The first step will be to obtain an Obstruction Clearance Chart for the particular site. It will be verified visually at the site, and any discrepencies will be noted. Parameters of height and position of obstructions will be entered into a computer prediction program which will show areas of expected blockage of signals from particular satellites. Flights will be conducted at those times and in those areas where blockage is expected to occur. Effects of obstructions of various sizes will be investigated. These may include large buildings which may produce intermittent coverage, or mountains which may completely block the signal. The aircraft will be flown off of published routes, if necessary, to document these effects. Flight test data will be correlated by position with the predicted blockage pattern to determine the conditions under which blockage occurs. This will help refine the model and verify the areas of blockage and signal availability.

Signal-to-noise ratios (SNR) of the GPS signal are subject to small variations due mainly to attenuation resulting from passage through the earth's atmosphere. At lower satellite elevations the path length through air is proportionately greater and SNR goes down. The satellites' antenna patterns are designed to compensate to some degree, but SNR variations due to lower signal levels will occur. They will be documented during this flight test and presented as plot data of SNR versus elevation angle.

TEST EQUIPMENT.

Several types of receivers will be made available for this flight test. They include one P code and two C/A code receivers. The P code set is a Phase II receiver manufactured by Collins Radio under the U.S. Air Force GPS User Equipment development contract. The C/A code receivers are a Magnavox Z-set built during Phase I, and a commercially available Litton LTN-700.

A number of Phase II receivers have been delivered to the Joint Program Office (JPO). They will be allocated to users based upon need and justification. The units are five-channel P code receivers built for the high dynamic military environment. They provide simultaneous tracking of four satellites for navigational use, leaving one channel for acquisition of satellites rising over the horizon. The receiver selects the satellites which will give the best navigational performance based upon geometry and signal availability. An instrumentation port is provided for control inputs and data outputs. The default mode outputs a predetermined block of data at a predetermined rate. This mode has been judged to be sufficient for the purpose of this test.

An interface control document for this type receiver is listed as item number 1 under "Related Documentation." The interface provided utilizes standardized blocks of data for output. Initial inspection of the types of parameters available has indicated that no modification of the units or their interfaces will be necessary. A list of parameters available from the Time Mark Data Block and the Midcourse Receiver Ephemerides Data Block are provided in table 1.

TABLE 1. DATA FORMAT BLOCK DATA SUMMARY, PHASE II RECEIVER

Time Mark Data Block

Data Item	Number of Parameters	Number of Words	Number of Units
GPS Time	1	4	Seconds
CUT Time	1	4	Seconds
Delta Time from GPS Time	1	1	10 Milliseconds
Time Mark Counter	1	1	N/A
Position (Lat, Long)	2	4	Radians
Position (x,y,z)	3	6	Meters
Altitude (m.s.l. and Absolute)	2	4	Meters
Velocity (E, N, Up)	3	6	Meters/seconds
Acceleration (E, N, Up)	3	6	Meters/sec/sec
Attitude (Pitch, Roll)	2	4	Radians
True Heading	1	2	Radians
Magnetic Variation	1	2	Radians
Measurement Channel Status	5	10	N/A
Standardized Figure of Merit	1	1	N/A
Expected Horizontal Error	1	1	Meters
Expected Vertical Error	1	1	Meters
Equipment Configuration	1	2	N/A

Midcourse Receiver Ephemerides Data Block

Data Item	Number of Parameters	Number of Words	Number of Units
GPS Time	1	4	Seconds
Satellite Number	1	1	N/A
Satellite Health Word	1	1	N/A
C/N	1	1	Decibel
Ephemeris Data (Subframes 1,2,3 without parity)	3 x 15	45	N/A
Ionospheric Correction	1	2	Meters

The Litton LTN-700 is a fast sequencing receiver which utilizes a single channel front end to track up to four satellites simultaneously. This approach was used to keep hardware costs low without sacrificing performance. This type of design also trades off signal strength for dynamic performance because of its hardware multiplexing technique. Approximately 6 decibels (dB) of signal strength available at the antenna is lost by the use of this architecture. The receiver provides serial data outputs through an RS-232 port and an ARINC-429 port. It may also be controlled through the RS-232 interface. The data available are listed in table 2.

TABLE 2. DATA FORMAT BLOCK DATA SUMMARY, LTN-700

Data Block	Period (sec)	Description
A	30	Almanac data (32 pages)
C	10	Covariances
E	30	Ephemeris data (6 pages)
K	1	Kalman filter States
L	1	Local level navigation data
M	1	Measurements from RPC
N	30	NAV, RPC, and satellite status
Q	1	CDU display
S	120	Satellite selection data
T	10	Accumulated delta-range
U	120	UTC and ionosphere data
Z	10	Kalman filter residuals

The Magnavox Z-set is a Phase I prototype which uses a single channel and sequential scanning. In this design the receiver tracks each satellite continuously for approximately 1 second at a time. It sequentially tracks up to four satellites which are included in the navigation solution. This design also minimizes hardware at the expense of software. No signal strength is lost, but the receiver will not perform as well in a dynamic environment as one that tracks multiple satellites at once. The Z-set interfaces to the PDP-11 UNIBUS and provides the data listed in table 3.

AREAS OF RESPONSIBILITY

APM-450: Provide funding and program management to ACT-140.

JPO: Provide user equipment hardware and integration support.

USCG: Provide interface to the Control Segment through Space Command.

YPG/GD: Provide technical assistance and supply available data as requested.

ACT-600: Provide aircraft and personnel to conduct flight test.

ACT-140: Write test plan, perform data analysis, design and build receiver interface and data collection system, and write final reports.

TABLE 3. MAJOR Z-SET RELATED PARAMETERS RECORDED

PZ:	Z-set derived position utilizing earth-centered earth-fixed (ECFD) coordinates converted to latitude, longitude, and altitude in WGS-72 coordinate system.
SN:	Number of each satellite in the constellation selected by the Z-set providing data.
NSD:	Number of satellites presenting providing data.
NSE:	Number of satellites for which ephemeris data has been collected.
DX,DY,DZ:	Difference between z-set derived position and the radar determined position of the aircraft beacon antenna in three orthogonal directions. DX is the northerly difference, DY is the easterly difference, and DZ is the altitude difference.
2D:	Horizontal difference between the Z-set derived position and the radar determined position of the aircraft beacon antenna.
GS:	Z-set derived ground speed.
GTK:	Z-set derived ground track.
Z (Dwell):	Z-set dwell counters for each satellite (increased for poor data quality, decreased with good data quality).
HDOP:	Horizontal dilution of precision value for satellite configuration selected.
GDOP:	Geometric dilution of precision value for satellite configuration selected.
EPE:	Estimated position error of the Z-set.
GPS (Time):	GPS time in tenths of seconds from the Z-set.

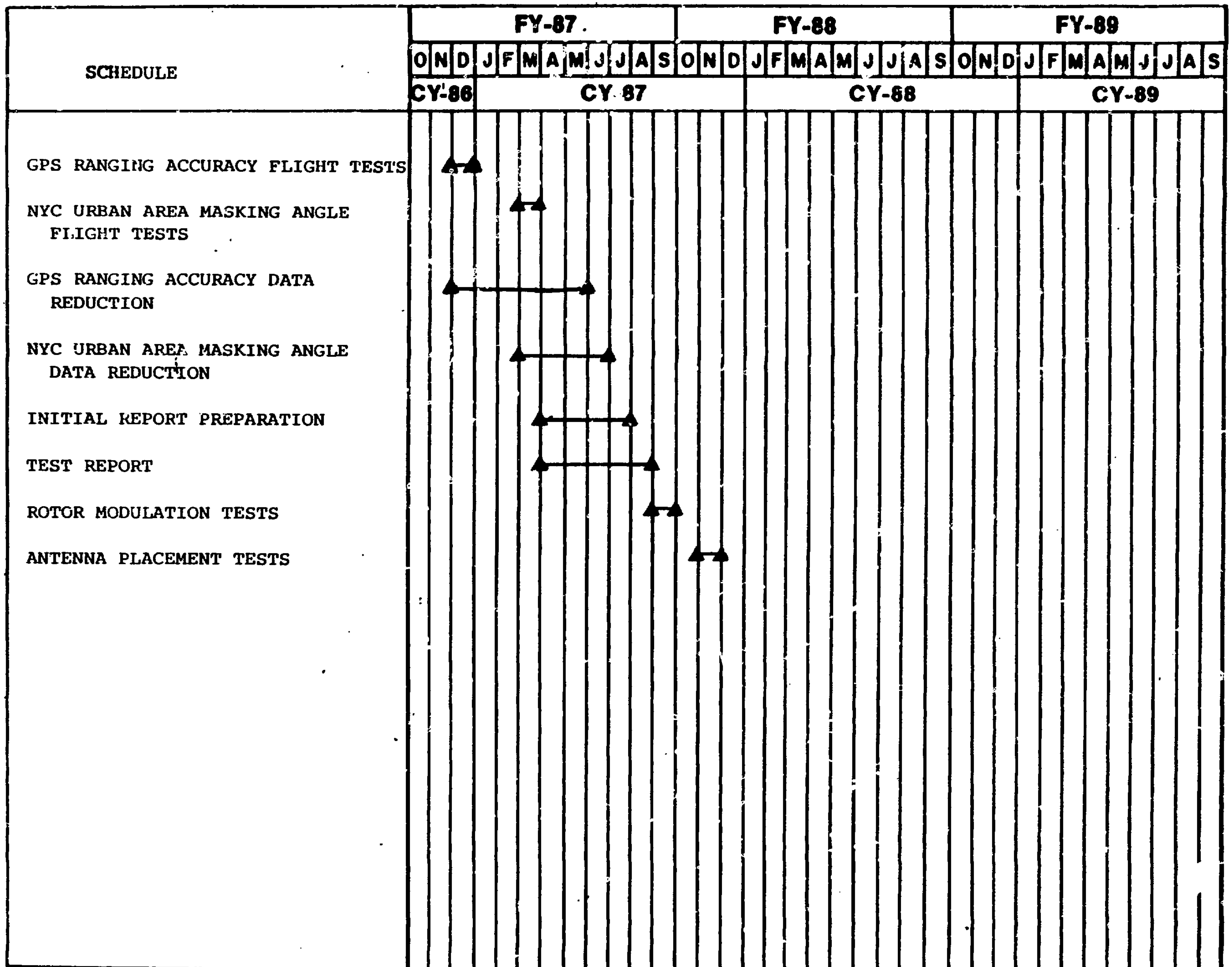
ANALYSIS OF RESULTS

Data will be statistically reduced and presented as mean and standard deviations for parameters of interest. These will include SNR and accuracy where available. Plot data will be provided which show areas of signal blockage due to obstructions and areas of multipath, if they can be identified.

Results obtained using the different receivers will be compared. Characteristics of the receivers which affect these results will also be identified and discussed.

Analysis of the results will be conducted to determine what masking angle is appropriate, based on performance. The performance of different antennas and receiver technologies will also be verified and/or discussed relative to expected theoretical results.

Multipath data will be reduced by comparing results with and without multipath interference. The existence of multipath will be verified using correlation techniques or by direct comparison of performance in and out of multipath. Results will be presented which show the areas and times where multipath can occur, relative to an obstruction, and quantify the effects on navigational performance.


SCHEDULE
FY-87
FY-88
FY-89
O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
CY-86
CY 87
CY-88
CY-89
GPS RANGING ACCURACY FLIGHT TESTS
NYC URBAN AREA MASKING ANGLE FLIGHT TESTS
GPS RANGING ACCURACY DATA REDUCTION
NYC URBAN AREA MASKING ANGLE DATA REDUCTION
INITIAL REPORT PREPARATION
TEST REPORT
ROTOR MODULATION TESTS
ANTENNA PLACEMENT TESTS

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